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AS A LANDING SYSTEM FOR MANNED SPACECRAFT

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DEVELOPMENT OF THE PARA-SAIL PARACHUTE AS A LANDING SYSTEM FOR MANNED SPACECRAFT

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SUMMARY

A

This paper summarizes the Para-Sail development program conducted by the Landing and Impact Systems Section of NASA Manned Spacecraft Center as a part of an overall effort to develop a land landing system for second generation spacecraft. The evolution of the Para-Sail parachute from its inception as a towable ascending parachute for sport through the development program leading to qualification testing as a part of a primary landing system is documented. In addition to the parachute development program, the phases of the system development program applicable to the Para-Sail are presented.

INTRODUCTION

The Para-Sail is a gliding parachute designed to wing and airfoil theories by Pierre LeMoigne of France. Forward speed is obtained by a series of ports, or slots, that exhaust air rearward. Special fabric of extremely low porosity allows utilization of a high percentage of escaping air for this purpose.

The original configuration, shown in figure 1, employed a central suspension line (centerline) which pulled the apex down to increase vertical drag area and decrease profile drag area. The canopy was designed as a towable ascending parachute for sport use. The front was slotted to facilitate canopy filling at the initiation of tow, and two stabilization panels were added below the skirt for directional stability during tow.

In the spring of 1962, the Assistant Director for Research and Development at Manned Spacecraft Center, Mr. Maxime A. Faget, saw a snapshot in a national magazine of the Para-Sail being towed and was impressed by the lift-to-drag ratio (L/D) indicated by the apparent tow angle. Mr. Faget requested that the Landing and Impact Systems Section investigate the potential of the Para-Sail as a controllable landing device for use on manned spacecraft.

In the consideration of a land landing system for spacecraft, the requirement existed at Manned Spacecraft Center for some means of offsetting horizontal drift induced by surface winds since it is difficult to provide impact attenuation in the horizontal direction. A gliding parachute could, by heading into the wind, negate a horizontal drift equal to its own forward speed.

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Two Para-Sail assemblies were purchased from the Pioneer Parachute Company, Manchester, Conn., which had obtained the license rights to the Para-Sail in the United States. These two assemblies were used for initial tow tests made July 20, 1962, at a small airfield near Houston, Texas. These tests showed that the canopy was stable, and the cotangent of the tow-rope angle indicated the lift-to-drag ratio (actually (L-W)/D) to be a surprisingly high 0.84. A quick look at the same parachute in the full-scale wind tunnel at NASA Ames Research Center produced a measured L/D of 0.96 at a tunnel velocity of 30 feet per second.

At that time the glidesail, with an L/D up to 0.7, represented the best gliding parachute known. Operational studies conducted by the Manned Spacecraft Center indicated an L/D of 1.0 was required to satisfy land landing requirements. With the original version of the Para-Sail representing a significant advance in the state-of-the-art of gliding parachutes, the decision was made to initiate a Para-Sail development program.

DISCUSSION

Since the inclusion of a central suspension line which pulled the apex down inside the canopy presented a shape basically different from standard parachutes, the Para-Sail deployment and inflation characteristics were recognized as an important unknown. It was also recognized that the extremely low porosity Para-Sail fabric would be conducive to high opening loads. In the development of a gliding parachute for a particular application, the normal practice is to select a standard canopy with good inflation characteristics and then develop the required steady-state performance with a series of stepwise modifications, taking care not to introduce modifications which compromise inflation. Since this effort started with a canopy design essentially capable of meeting the steady-state-performance requirements, it was necessary to plan a program designed to develop inflation techniques and to correct design deficiencies affecting inflation without compromising steady-state performance.

In September and October of 1962, seventeen low-speed deployment tests of 23.2-foot-diameter canopies were conducted at the Manned Spacecraft Center. For this initial series, the Para-Sail was deployed with the centerline extended to permit normal "apex up" inflation. These deployment tests were successful although the front of the canopy exhibited a tendency to tuck-in during inflation.

In conjunction with these deployment tests, the University of Minnesota began a wind-tunnel evaluation of approximately 4-foot-diameter models in an effort to achieve a maximum L/D of at least 1.0. In December 1962, a Para-Sail model on which the front had been replaced with solid panels exhibited an L/D of 1.2.

On the basis of information gained up to this point, a program was initiated through Pioneer Parachute Company to investigate the inflation characteristics and performance of an 80-foot-diameter version of the Para-Sail.

EVOLUTION OF 80-FOOT-DIAMETER PARA-SAIL CONFIGURATION

Development of the large Para-Sail parachute has been a joint effort among Manned Spacecraft Center, Pioneer Parachute Co., and the University of Minnesota, with most of the exploratory work being conducted by the Manned Spacecraft Center at Houston. The initial 80-foot-diameter configuration shown in figure 2 featured rear and side exhaust slots, two rows of turn slots on each side, the centerline, and a scooped front similar to the original towable configuration. When drop-tested, the slotted front exhibited a serious front tuck-in characteristic during inflation. While this same tendency had been evident in tests of the 23.2-foot-diameter canopies, it had been of short duration and the front panels would pop out to a fully inflated state. This was not always true of the larger canopy. As inflation began, the rear half of the canopy would open immediately, begin to glide, and drive over the front half. This tuck-in condition sometimes resulted in inversion. The addition of a pilot parachute with a 36-line bridle permanently attached to loops on the doughnut-shaped crown area aided greatly in preventing inversion but did not solve the basic aerodynamic tuck-in problem.

The decision was made to replace the slotted front with solid panels, and based on a solid-front configuration study made with 24-foot-diameter canopies, a semi-elliptical cutout was added to the front lip. Wind-tunnel studies at the University of Minnesota indicated that this modification slightly increased L/D and did not adversely affect the rate of descent or stability. Drop tests of the 80-foot solid-front configuration showed a decrease in magnitude of the tuck-in but not an elimination of the basic tendency. The addition of pocket bands was ineffective.

At this time the University of Minnesota was directed to make a wind-tunnel investigation of the effect of an internal parachute as an inflation aid. When these studies proved favorable, a 10-foot guide surface internal parachute was added to the system. Results of drop tests with the internal parachute showed great improvement in both reefed shape and inflation after disreef.

During a series of tests conducted at MSC at Houston, Texas, the deployment and inflation characteristics sufficiently improved to warrant extensive testing at Joint Parachute Test Facility, El Centro, Calif. When the last test at Houston and the initial four tests at El Centro showed that opening loads were excessive, the effect of removing the centerline was investigated. The results of these studies indicated that opening loads would be reduced, that L/D and stability were not adversely affected, and that the increase in rate of descent would be negligible.

Based on these results, an existing 80-foot-diameter canopy was modified for drop testing with the centerline removed. Film coverage of this test indicates the deployment behavior of the Para-Sail without the centerline was similar to that of a ringsail canopy, that is, large reefed airball and rapid opening after disreef. Trajectory data indicated L/D to be approximately 1.15, with an insignificant increase in rate of descent.

Tests to this time had been conducted at altitudes up to 5,000 feet, suspended weights up to 3,700 pounds, and dynamic pressures up to 50 pounds per square foot. Figure 3 shows the configuration at this stage with the original scooped rear, a solid front with a semi-elliptical cutout in the skirt, two rows of turn slots on each side, no centerline, a nearly flat circular crown, a 10-foot guide surface internal parachute, and a 6-foot pilot parachute permanently attached to the apex of the Para-Sail.

Follow-on tests increased altitude up to 10,600 feet, weight to 4,750 pounds, and dynamic pressure to 64 pounds per square foot. At this test condition another deployment problem arose. In all prior tests the stabilization panels had been tightly folded and tied off with breakcord. During two tests, as the stabilization panels emerged from the bag during strip-off, the breakcords failed and the stabilization panels inflated, causing partial canopy inversion and heavy damage during opening.

A two-phase study was initiated to determine the effect of removal of the stabilization panels on steady-state performance and to develop a means for controlled retention of the stabilization panels during deployment. A drop test of the 80-foot-diameter Para-Sail without stabilization panels showed a slight reduction in L/D and an 8- to 10-percent increase in rate of descent. Drop tests of 24-foot-diameter canopies indicated that controlled retention of the stabilization panels by zero length reefing with short time delay cutters was feasible. This panel retaining system was incorporated into full-scale testing with satisfactory results.

The initial drop test program concluded with satisfactory deployment from 10,600 feet at a dynamic pressure of 80 pounds per square foot with a 4,750-pound payload.

SYSTEM DEVELOPMENT

In January 1963, the Landing and Impact Systems Section was directed to investigate and develop a landing system providing land landing capability for second generation spacecraft. The system incorporated the Para-Sail for local obstacle avoidance and negation of horizontal drift due to surface winds and retrograde rockets fired close to the ground to reduce descent velocity prior to touchdown. In order to utilize the capability of the canopy, it was necessary to develop a control mechanism providing both directional control and modulation of forward glide. Since effectiveness of the rockets is dependent on ignition at a precise ground clearance altitude, it was also necessary to develop a sophisticated altitude sensor.

Concurrent with drop tests of the 80-foot-diameter Para-Sail, development programs in other component areas and scale-model system tests were initiated. The following section summarizes the phases of the system development program applicable to the Para-Sail.

TEST PROGRAMS

Tests of One-Third-Scale Systems

Prior to full-scale tests of a Gemini-type vehicle, a model test program was established to obtain preliminary system data. The primary objectives of this program were to investigate the dynamic behavior of the vehicle-parachute combination; determine the load distribution of the Para-Sail, control line forces, and response of the system to control inputs; and evaluate the visual references required for full utilization of the glide and maneuver capabilities.

Figure 4 shows the 1/3-scale system with an early version of the Para-Sail which was used for the first 18 tests. On the last seven tests the canopy was modified to the solid front, semi-elliptical cutout configuration.

The test vehicle was a 1/3-scale model of the Gemini spacecraft made of a steel tubing frame covered with a 1/8-inch fiberglas shell. When fully instrumented the vehicle weighed approximately 350 pounds. Impact attenuation was achieved through honeycomb struts during early tests and later by a yielding-metal type gear. The parachute was attached to the vehicle by two rear risers, two front risers at a single attach point, and the centerline.

Instrumentation included three 16-mm movie cameras and a 12-channel oscillograph. Riser loads, control-line forces, and impact accelerations were measured. Static pressure was also measured to provide a rough indication of rate of descent.

The drop tests were conducted from a UH-19 helicopter at altitudes ranging from 900 to 4,000 feet. Drop speeds ranged from 15 to 30 knots. The parachute control system was actuated by ground radio commands. Following full inflation a series of pre-planned turns was normally executed, and prior to impact the vehicle was turned into the wind to reduce horizontal velocity.

The slotted front canopy, using single turn vents, attained turn rates of about 12 deg/sec and angular accelerations of 4 deg/sec^2. The modified canopy used during the final eight drops achieved a maximum turn rate of 70 deg/sec and an angular acceleration of 12 deg/sec^2. It should be pointed out that these accelerations are affected by the speed at which the turn lines are "pulled in." It was also determined that simultaneous actuation of both turn lines to produce forward exhaust through the turn slots was effective in modulating lift-to-drag ratio.

The rate of descent averaged 18 feet per second. Although no quantitative trajectory data were obtained, analysis of film and observations of the ability to overcome known winds indicate an L/D of approximately 1.2.

In this test series, the slotted-front configuration exhibited the characteristic front tuck-in during inflation. This tendency was considerably reduced in those tests using the solid-front canopy.

The canopy-vehicle combination proved quite stable, with oscillations of less than 5° about all three axes during "straight and level" flight. During low rate turns there was very little effect on system stability; however, the 70 deg/sec turns produced changes in roll attitude of the vehicle by as much as 30° and pitch down of the canopy of about 10°. The change in vehicle roll attitude was apparently caused by the tendency of the vehicle to travel in a straight path while the canopy turned away from it. At this high turn rate, the canopy "banks" into a turn, rotating the lift vector off the vertical, which increases the rate of descent by approximately 20 percent.

Tow Program

The tow program consists of ground tow tests of a 2/3-scale Gemini vehicle (shown in fig. 5 with a dummy occupant) incorporating a 40-foot-diameter Para-Sail and a manual control system. This program includes the investigation of control systems, canopy control methods, control system-parachute interface, control response, pilot visual requirements, and techniques.

This system is currently undergoing an extensive series of crane drop tests and towed and released flights. An instrumented dummy is included in order to qualify the system for manned flight. After qualification, the vehicle, with a single occupant, will be towed to altitudes up to 600 feet, then released for free descent in which the pilot "flies" the vehicle back to earth by means of a stick and rudder pedal control system. Since preparation for test can be accomplished in a matter of minutes, it will be possible to accomplish several flights in one test day.

Gemini Boilerplate Drop-Test Series

In the Gemini boilerplate drop-test series, now underway, the various components are phased into full-scale systems testing. The basic components to be included are a Gemini boilerplate vehicle, an 80-foot-diameter Para-Sail, a radio command actuated canopy control system, landing rockets, an altitude sensor, prototype Gemini landing gear, and a television system for simulation of pilot view. The vehicle is instrumented with onboard magnetic tape recording and telemetry to acquire the full range of flight data.

In this test series, the parachute is deployed from the separated rendezvous and recovery canister with the vehicle in a reentry attitude. After full inflation, the vehicle changes from reentry to landing attitude (fig. 6).

PLANNED DEVELOPMENT

The Manned Spacecraft Center is initiating a program of final development and qualification of the Para-Sail parachute. In this program the canopy must meet the following performance parameters:

Suspended weight, lb	4,750
Deployment altitude, ft	10,600
Deployment dynamic pressure (design), lb/sq ft	80
Rate of descent, (at 5,000-foot pressure altitude), ft/sec	30
Maximum lift-to-drag ratio	1.0 (at least)
Minimum rate of turn, deg/sec	10
Stability, maximum oscillation, deg	±3
Ultimate strength capability, design dynamic pressure	1.5 (120 lb/sq ft)
Maximum opening force, (design dynamic pressure), lb	16,000

All canopy development and qualification tests will be conducted at El Centro. After canopy qualification, the Para-Sail will be included in system qualification testing.

OTHER APPLICATIONS

The Manned Spacecraft Center has employed the 24-foot-diameter Para-Sail as a means of training the astronaut flight crews in parachute familiarization. In this program trainees were towed to altitudes up to 900 feet, then released for normal parachute descent. This training included both land and water phases.

Following the successful completion of this training, the Air Force indicated an interest in instituting a similar program at the Crew Training School, Tyndall Field, Florida. The Manned Spacecraft Center has been asked to furnish technical assistance in the formulation of this program.

At the request of the Air Force, the Manned Spacecraft Center incorporated the Sandia homing beacon into the 1/3-scale system and successfully demonstrated the capability of the Para-Sail as a homing cargo delivery parachute.

This concludes the lecture phase of the presentation. A 5-minute film depicting milestones in the development program will now be shown.

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Figure 1.- Original 23.2-ft diameter Para-Sail.

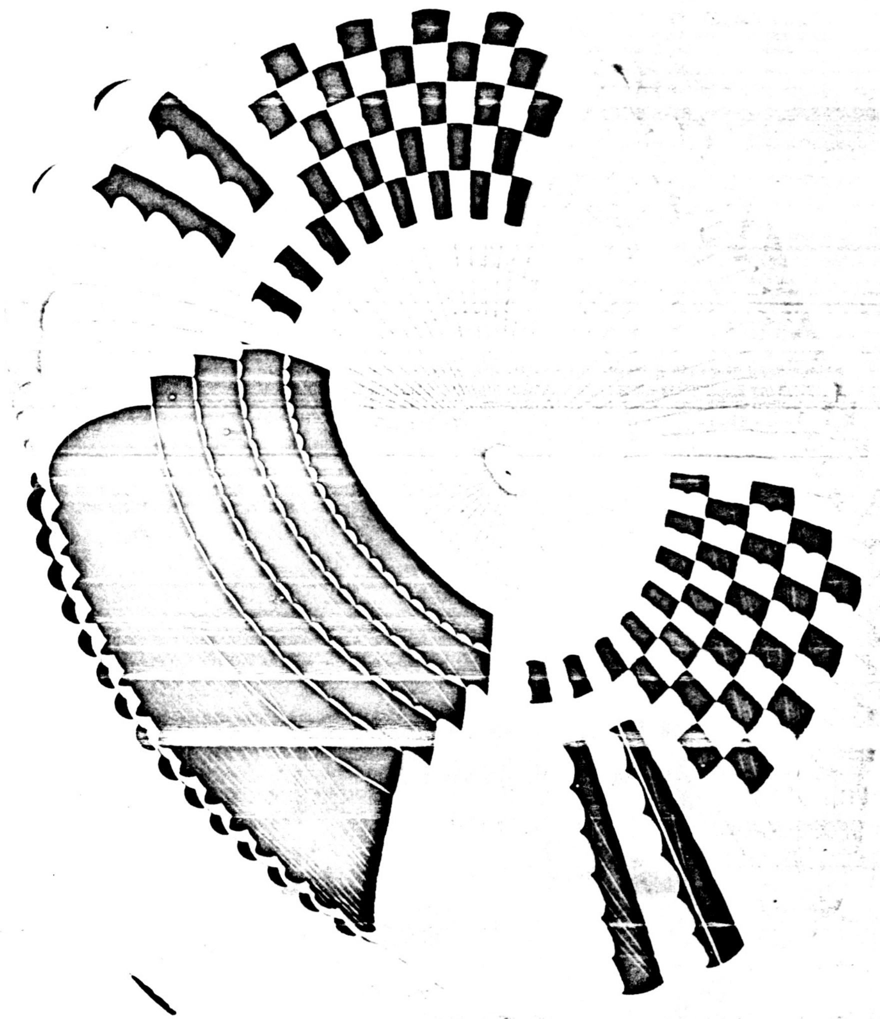

Figure 2.- Original 80-ft diameter Para-Sail.

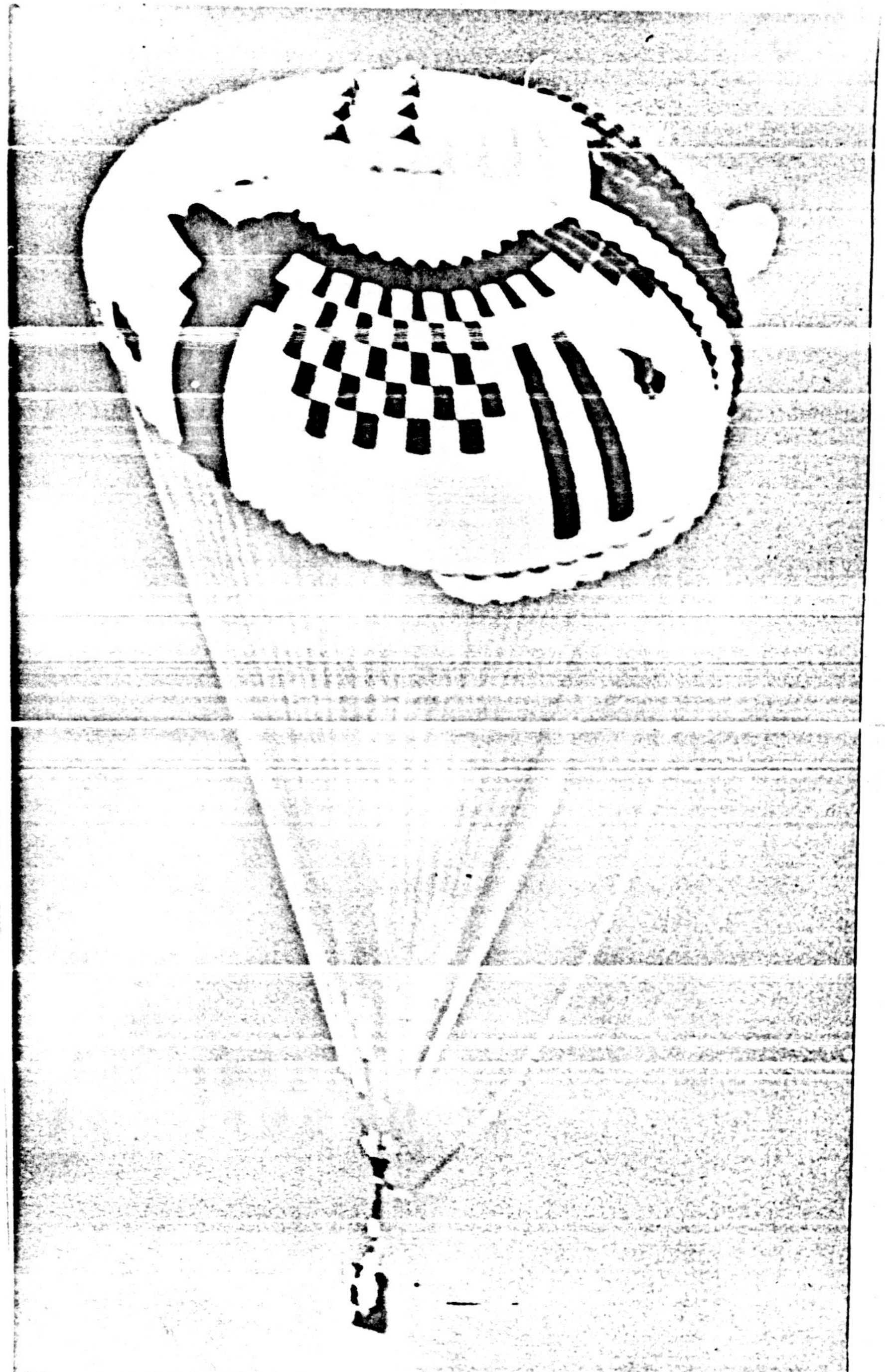

Figure 3.- Current 80-ft diameter Para-
Sail configuration.

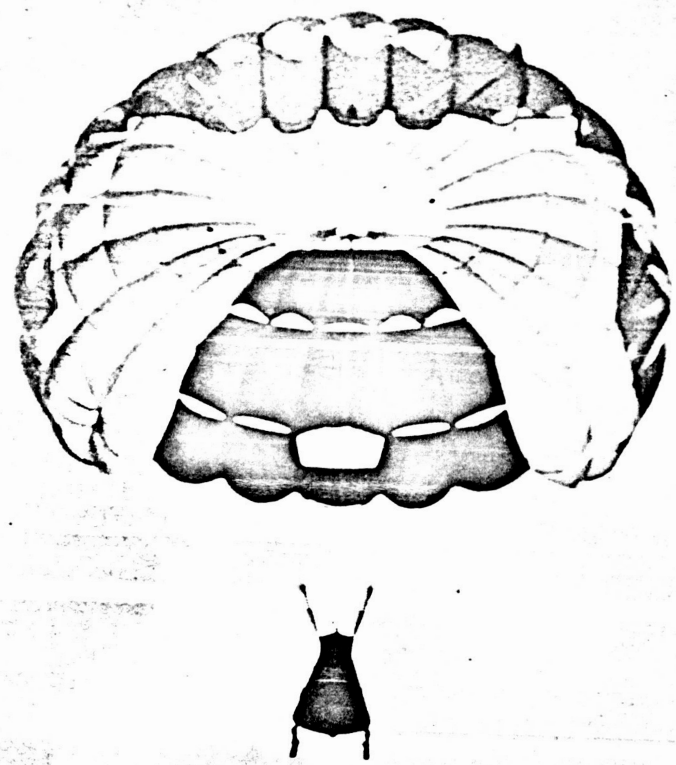

Figure 4.- $\frac{1}{3}$ scale Gemini system.

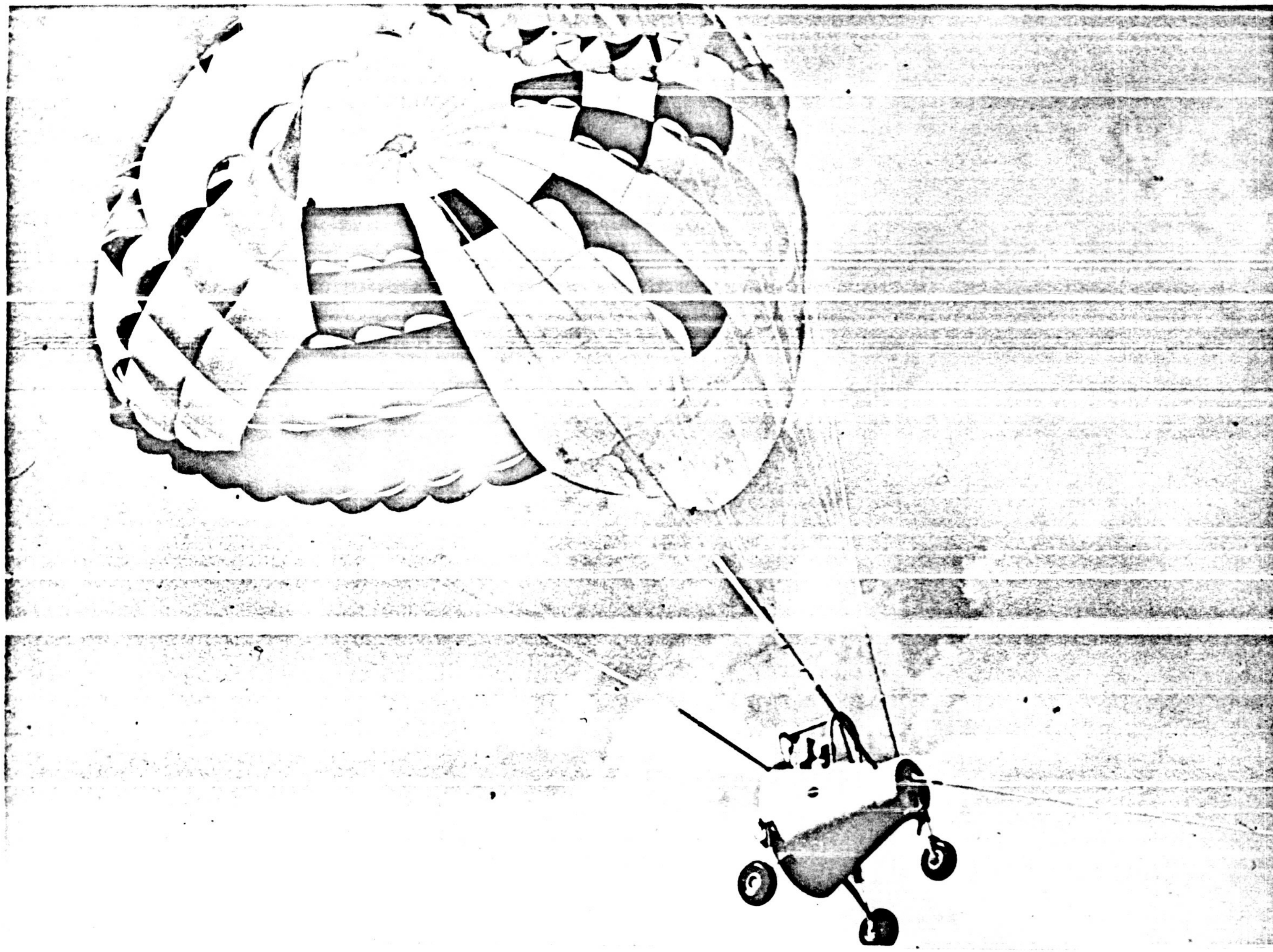

Figure 5.- Tow vehicle.

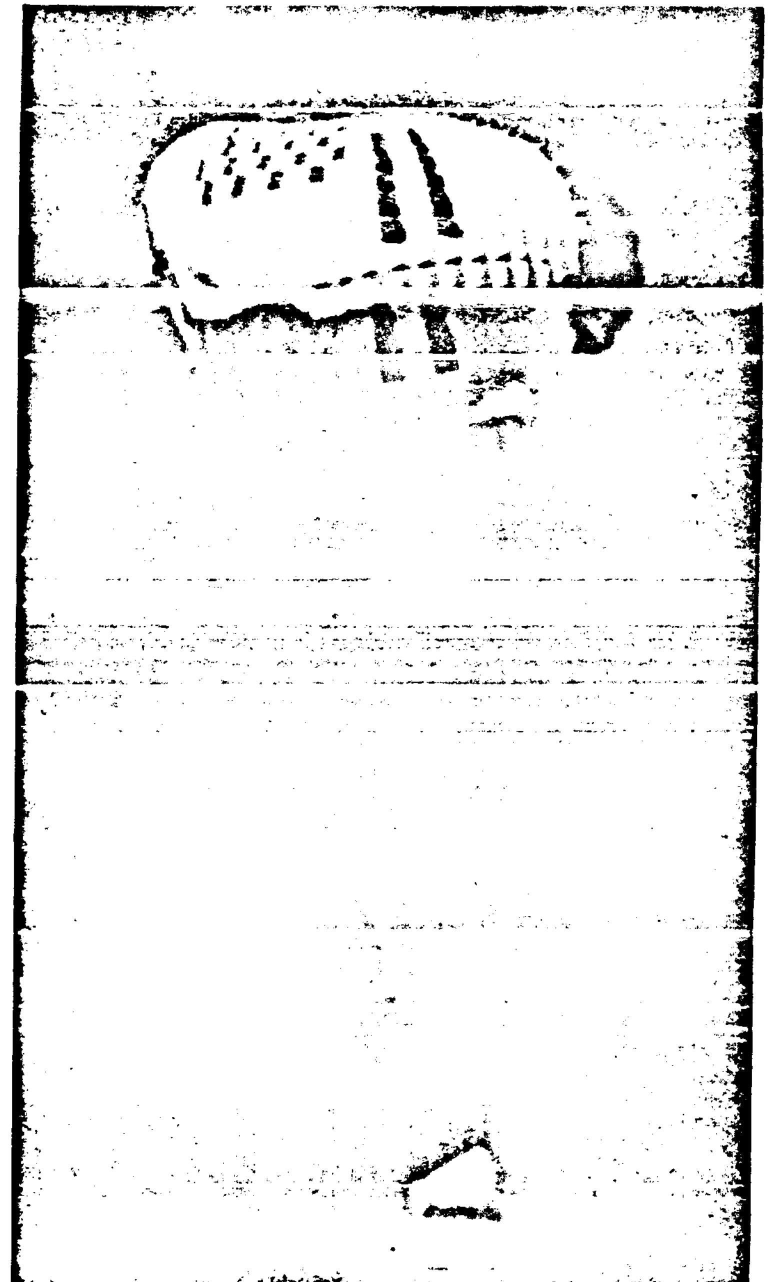

Figure 6.- Full scale boilerplate
landing system.